

ATLAAS: A model for optimal auto-segmentation of PET images in RT planning

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**Purpose/Objective:** Positron Emission Tomography auto-segmentation (PET-AS) methods can provide reliable and reproducible segmentations of the Gross Tumour Volume for radiotherapy planning. However, a large variety of PET-AS methods have been validated on different datasets, making it difficult to recommend a single algorithm. We present a Predictive Model for optimal auto-segmentation of PET images based on machine learning technology. The ATLAAS package (Automatic decision Tree Learning Algorithm for Advanced Segmentation) can select and apply the best PET-AS algorithm from a pool of methods on which it has been trained.

**Materials and Methods:** For each PET-AS included in the model, ATLAAS predicts its accuracy in segmenting a given target lesion. This is based on the analysis of several image parameters describing the lesion. The prediction is done using a set of rules (decision tree) derived by training ATLAAS on a large number of synthetic images representing realistic data generated using a fast PET Simulator. The accuracy of the PET-AS is quantified with the Dice Similarity Coefficient (DSC), using the known ground truth extracted from the synthetic lesion. A total of 25 PET-AS algorithms are currently implemented in ATLAAS. These include adaptive thresholding, region-growing, gradient-based and clustering methods. ATLAAS was optimized for H&N and was built using more than 1000 images. The validation of ATLAAS was carried out on 115 PET scans acquired using fillable spherical and non-spherical inserts and printed subresolution sandwich phantoms. Both homogeneous and heterogeneous uptakes were modeled. The segmentation of 10 H&N patients with ATLAAS was also compared to manual delineation carried out on PET/CT data.

**Results:** Nine image parameters were used in the ATLAAS predictive model, including the lesion volume, peak intensity, peak-to-background ratio, coefficient of variation, regional Haralick texture features and geometrical complexity indices. The mean accuracy of the decision tree method was 0.82 DSC for the phantom dataset, with a range of 0.36-0.96. In 80% of the cases, our method selected an algorithm providing a DSC within 5% of the best DSC across algorithms. The average DSC comparing the results of ATLAAS to manual PET/CT segmentation was 0.70, ranging between 0.65 and 0.92. Differences were mainly due to absence of CT component in ATLAAS.

**Conclusions:** We have developed a method that identified the most accurate auto-segmentation algorithm for FDG PET images. The accuracy and robustness of ATLAAS has been shown on a large range of synthetic and experimental data. ATLAAS is a useful tool for optimal segmentation of PET images used for RT planning and can be further optimized to include different anatomical regions and tracers. Patent pending.

Testing the C-RAD Catalyst elastic image registration software using a deformable female phantom

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**Purpose/Objective:** C-RAD Catalyst is a recently introduced system that uses a patient's optical maps to check positioning and to manage intra-fraction motion. One of its key feature is the possibility to perform elastic registration. Since the patient's external surface can easily be deformed during the course of treatment, a deformable registration algorithm could potentially provide a more accurate target volume registration than a global rigid approach.

In this study, we propose a quantitative validation of the deformable image registration algorithm implemented in Catalyst. The validation has been performed using Portal Images (PI), and a deformable female phantom, 'Sliced Mary', designed and developed expressly for this project.

**Materials and Methods:** Phantom: 'Sliced Mary' is a deformable phantom, containing anatomical structures and hidden targets, designed for both optical and x-ray imaging (Figure). The phantom was made of 30 slices held together by a rope running inside the phantom. Arms were also constructed and fixed to the phantom torso. The sliced phantom was finally covered with a white tissue. Independent and realistic head rotation, arms flexion as well as body torsion around a longitudinal axis and bending around lateral and vertical axes can be achieved.

**Tests:** A CT acquisition of 'Sliced Mary' was performed and, for each target, AP and LL DRRs were created and sent to iViewGT (Elekta PI system). The external phantom surface and RT plans, one for each target, were sent to Catalyst. The phantom was put on the linac couch with the isocentre positioned on the target that simulates a breast lesion, and 5 head and left arm displacements were applied. PI and Catalyst acquisitions were performed and the registration results were compared.

Bending of Sliced Mary's body around lateral and vertical axes were then applied. The linac isocentre was positioned on each target, and PI and Catalyst registration results were compared. When elastic deformations occur, the iViewGT global rigid registration algorithm can provide registration parameters valid only for a part and not for the entire image. Privileging the target registration instead of the surrounding anatomical structures, it is possible to obtain a local rigid transformation that should enable the best target set-up.

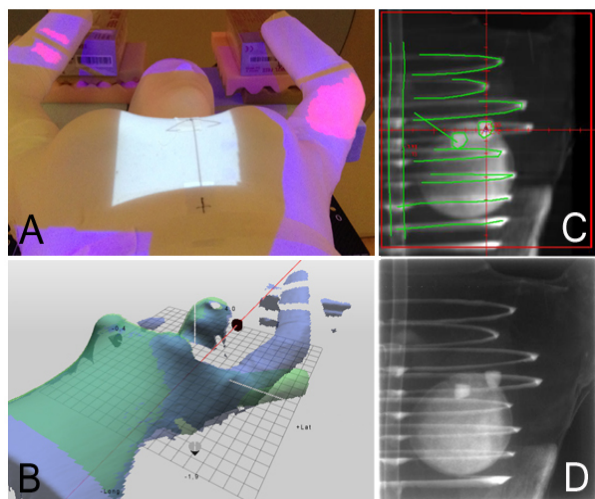


Figure: A) Picture of Sliced Mary during a Catalyst acquisition; B) External phantom surface; C) DRR; D) PI

**Results:** In the Table the differences between iViewGT and Catalyst registration parameters are reported for all the elastic misalignments considered. No influence of head rotations on breast target registration parameters is evident whereas a little dependence from the left arm flexion is observed. When bending around lateral and vertical axes are considered, differences between Catalyst and iViewGT, dependent from targets position, are observed.

Breast target Head rotation						Breast target Left arm flexion					
head rot.	Lat [mm]	Long [mm]	Vert [mm]	Rot [°]	Pitch [°]	arm rot.	Lat [mm]	Long [mm]	Vert [mm]	Rot [°]	Pitch [°]
0°	-0.3	0.75	0.2	-0.3	0.1	18°	-1.1	1.05	0.5	0.1	0.3
6°	0.3	0.1	-0.1	-0.4	0	22°	1	-1.5	0.8	0.5	0.9
7°	-0.7	0.2	-0.1	0.2	0.3	35°	0.2	-2.8	1.9	-0.2	1.1
10°	0.4	-0.2	-0.7	0.3	0.4	44°	0.2	-2.4	1.5	-0.2	1.4
36°	0.1	-0.6	-0.1	-0.3	0.7	45°	-1.1	1.05	0.5	0.1	0.3
Bending around lateral axis (8°) Range of differences for all targets						Bending around vertical axis (6°) Range of differences for all targets					
	Lat [mm]	Long [mm]	Vert [mm]	Rot [°]	Pitch [°]		Lat [mm]	Long [mm]	Vert [mm]	Rot [°]	Pitch [°]
min	-2.5	-1.45	-4.5	-0.2	0.6	min	-3.7	-1.85	-2.7	-0.4	-11.8
max	1.6	4.25	4.10	2.8	1.4	max	2.6	1.65	2.7	1.2	-0.4

Table: Differences between iViewGT and Catalyst registration parameters. Roll is not detectable in PI.

**Conclusions:** The deformable image registration algorithm implemented in Catalyst has shown accurate performances especially for targets which are closed to the bending axis and far from the deformed region.

**Poster: Physics track: Implementation of technology, techniques, clinical protocols or trials (including QA and audit)**

PO-0979

Fragmentation cross sections on thin targets using  $^{12}\text{C}$  ions

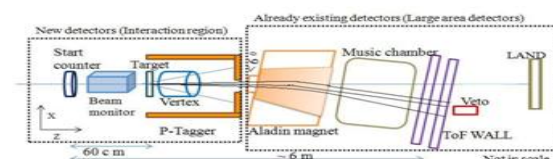
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**Purpose/Objective:** The FIRST (Fragmentation of Ions Relevant for Space and Therapy) experiment at the Helmholtz Center for Heavy Ion research (GSI) was designed and built by an international collaboration from France,

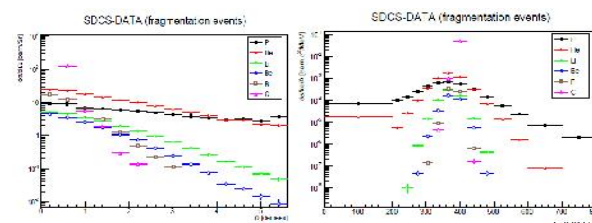
Germany, Italy and Spain for studying the collisions of a  $^{12}\text{C}$  ion beam with carbon and gold thin targets. The experiment main purpose is to provide the first measurement of double differential cross section measurement of carbon ion fragmentation at energies that are relevant both for tumor therapy and space radiation protection applications. The SIS (heavy ion synchrotron) was used to accelerate the  $^{12}\text{C}$  ions at the energy of 400 MeV/u: this energy is particularly interesting for particle therapy applications, where  $^{12}\text{C}$  ions of such energy are used for the treatment of deep seated tumors.

**Materials and Methods:** Fragmentation cross sections are measured in FIRST using an experimental setup with several detectors, already described in [1, 2] that has been designed and optimized using a dedicated MC simulation. The schematic view of the FIRST experimental setup is shown in Fig.1, together with the axis orientation of the reference frame.



**Figure1.** Top view (x,z plane) of the FIRST experiment. From left to right: the beam pipe after the last collimator and the beam exit window; the table supporting the Start counter, the Beam Monitor and the Vertex detectors, enclosing the target holder; the P-Tagger calorimeter, just before the magnet entrance window; the ALADIN magnet region; the ToF Wall detector at the right most position.

**Results:** A proper calibration of all the detectors is essential to reach the required accuracy in the determination of the kinematic variables and the separation of fragments of different charges and masses. Preliminary results for cross sections as a function of the polar angle and in kinetic energy for different fragments are shown below.



**Conclusions:** The FIRST experiment performed a measurement of SDCS, as a function of fragment angles and kinetic energies, studying a data sample of several million collisions of  $^{12}\text{C}$  ions impinging on a thin (8 mm) carbon target. This is the first measurement ever made, in such experimental configuration, performed with an ion energy of 400 MeV/u, that is particularly interesting for particle therapy and space applications. The result presented here is systematically dominated and covers only a limited angular range: a refined analysis, to be performed in the full angular range accessible to the experiment is in preparation.